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A simulation of the capability of multispectral infrared imaging for thermographic inspection of multi-material systems

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Abstract

The usage of multi-material systems is increasing just as the customization of industrial products right inside the fabrication process. As different materials and surfaces have a very characteristic interaction with infrared radiation, implications for the usability of thermography for quality control or monitoring setups are substantial. Multispectral imaging approaches are promising to overcome the constraints of an uncertain or unknown emissivity coefficient. A simulation is presented that can illustrate their capability and emphasize their value for non-destructive testing and monitoring.

1. Introduction

By preference, infrared thermography is applicable these days for convenient objects with well-defined surface, achieved by pretreatment or black lacquering. Especially for monitoring setups in variable environment, multispectral imaging approaches are promising to overcome the constraints of an uncertain or unknown emissivity coefficient. They are widely used in airborne or satellite-based remote sensing [1] but cannot be translated directly. Nevertheless, for non-destructive testing in laboratory or industrial production, an increasing demand can be predicted because of the transformation towards tailor-made multi-material systems and highly customized industrial products in small batch sizes.

Carbon fibre reinforced composites (CFRP) are material systems already widely used in several industries. At their surface, thickness of resin and carbon fibres is alternating. This leads to an inhomogeneous emission which superimposes the heat sources and distribution caused by internal flaws that shall be examined. The author was able to apply a method using a dual-band camera to increase contrast and reveal details in an earlier work [2]. Now, the phenomenon is investigated by a simulation of the physical fundamentals.

2. Methodology for simulation

Parameter studies concerning different scenes, materials and spectral bands of observation can be conducted by the simulation. Any material of which the wavelength dependent emissivity curve is available can be simulated. The focus in this work is to show the capabilities of the multispectral approach, so the scene and material are kept constant. For illustration, an arbitrary material composition is considered here. Results can also be presented for a selection of real materials.

2.1. Image composition

Material 1 has a constant emissivity of 0.9 up to 6 µm wavelength declining to 0.8 in the LWIR. Material 2 has a constant emissivity of 0.7 up to 3 µm, 0.8 from 4.5 to 6 µm, 0.6 from 8 µm and a continuous progress in between. The material composition for the scene is a line grating. Heat distribution is a gradient from 20 °C (black) to 25 °C (white). Reflecting objects in the background are represented by a geometric shape with higher and lower temperature (Figure 1). The input masks of material ε, heat T and ambient heat T_a are evaluated pixel by pixel to calculate the radiance L in a spectral band λ according to the simplified radiation equation Eq. (1). Spectral bands are varied by a Monte-Carlo simulation.

$$L(T,\varepsilon) = \varepsilon_\lambda \cdot \int_{\lambda_-}^{\lambda_+} \frac{c_{1L}}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{c_2}{\lambda T}\right)-1} d\lambda + (1-\varepsilon_\lambda) \cdot \int_{\lambda_-}^{\lambda_+} \frac{c_{1L}}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{c_2}{\lambda T_a}\right)-1} d\lambda \qquad (1)$$

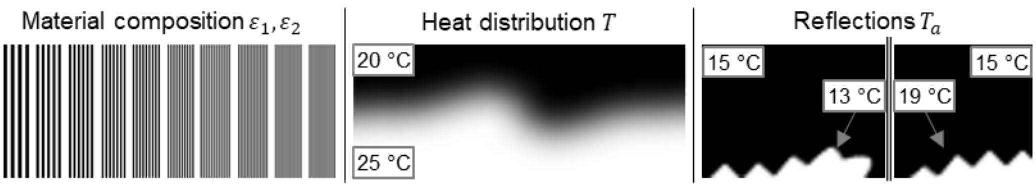

Fig. 1. *Input masks ε, T and T_a for radiance image composition.*

2.2. Image processing, quality assessment and comparison

Input noise can be added before calculation of radiance L. Camera noise is also added considering the NETD (noise equivalent temperature difference) of the simulated system. Simulated radiance images are processed according to the spectral ratio method already used in [2] and also by a difference image calculation.

A full-reference Image Quality Assessment (IQA) is implemented in the simulation to compare the results after image processing with the ground-truth assumed for the simulated scene. Assessment criteria are the Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM). The data can be visualised in different kinds.

3. Results and discussion

Figure 2 shows a Monte-Carlo simulation with 24 runs simulating an acquisition of the scene in two spectral bands lambda. This leads to four different images in each run: the acquired images and the results of processing them by ratio and difference image method. It is possible to find two spectral bands where processing can highly increase contrast (Figure 2). It is also remarkable that the acquired images did not exceed a SSIM value of 0.4 in any of the simulations. Higher values could only be reached by the spectral ratio or difference image.

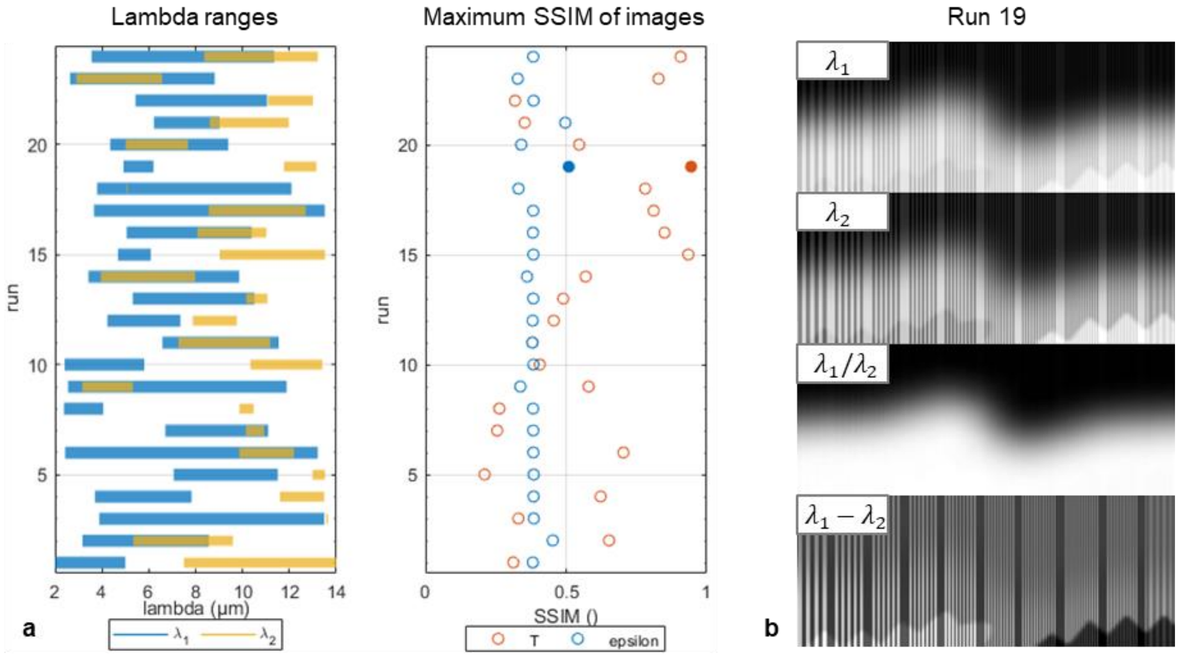

Fig. 2. *a) Simulation results: lambda ranges of acquisition and best SSIM of the four images, b) images of run 19. This run has both the maximum recognizability of heat distribution (ratio image) and material distribution (difference image).*

4. Summary

In this work, a simulation of infrared radiation in a non-destructive testing situation was implemented and a parameter study concerning the spectral bands of observation was carried out. The results were investigated regarding the capability of multispectral infrared imaging to enhance contrast or even decompose the underlying information of heat distribution, surface emission and reflected objects. The technique can successfully close the feature gap between monochromatic thermography of today and the ambition of hyperspectral imaging and shows promising future prospects to apply infrared thermography in expanding use-cases.

REFERENCES

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